AeroDynamic ADVISORY

AAM Supply Chain Considerations

9 September 2021

PREPARED FOR

AAM Supply Chain Working Group

Aerospace Supply Chain Overview

Aircraft Development Programs – Lessons Learned

Potential Supply Chain Bottlenecks & Conclusions

There are three end-user segments in aviation

Air Transport

- Includes cargo and passenger aircraft
- Aircraft categories are turboprops, regional jets, narrowbodies, and widebodies

Military

- Includes fixed wing and rotary wing military aircraft
- Includes fighters, tactical and strategic transports, attack and transport helicopters, and others

Business Aviation

- Includes helicopters and fixed wing aircraft used for business aviation
- Includes helicopters, turboprops, light jets, and large cabin jets

Source: AeroDynamic Advisory

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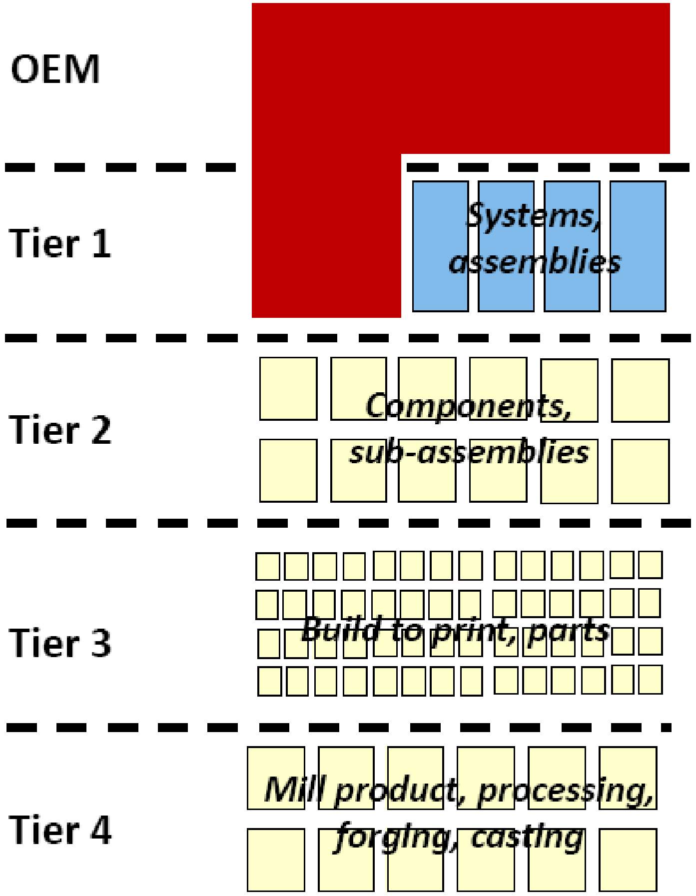
The aerospace supply chain is typically categorized into four tiers based on supplier products and capabilities



- Aircraft and engine OEMs generally have separate supply chains

- Tier 1 suppliers are typically responsible for large systems work packages or structrures assemblies
- They generally have design-build responsibilities

- Tier 2 suppliers provide individual components or parts
- They typically have design engineering capability

- Tier 3 suppliers are build-to-print suppliers
- They produce components and structures parts but typically have no design capability

- Tier 4 suppliers provide raw materials and processing
- This includes mill product, composite raw materials, processing and surface treatment, casting, forging, extrusion, etc.

AeroDynamic Advisory typically segments aircraft components (and their supply chains) into five categories

Aerostructures

Nacelle
- Engine Pylon
- Exhaust cone & nozzle
- Fan cowls
- Inlet cowls
- Thrust reverser

Wings
- Fixed leading and trailing edges
- Wing boxes
- Slats & flaps
- Ailerons & spoilers

Empennage
- Elevator & rudder
- Horizontal stabilizer
- Vertical stabilizer

Mechanical Hardware
- Standards
- Fasteners
- Fittings
- Seals

Fuselage
- Nose
- Forward
- Center
- Aft
- Fairings
- Doors
- Windows

Stuffing
- Insulation
- Ducts

Aircraft Systems

Actuation & Flight Controls
- Primary controls
- Secondary controls
- Utility controls
- Flight control computer

Electrical
- Generators
- Batteries
- Primary distribution
- Secondary distribution
- Power conditioning
- Ram air turbine
- Harnesses

APU
- APU
- Accessories

Fuel Systems
- Metering
- Pumps
- Valves
- Inerting
- Fuel management
- Conveyance

Emergency
- Air masks & oxygen
- Slides & rafts
- Fire detection and suppression

Pneumatics
- Environmental control system
- Air distribution
- Avionics cooling
- Bleed air/anti-ice
- Cabin pressure
- Heating
- Ventilation

Hydraulics
- Filters
- Motors/cylinders
- Pumps
- Reservoirs/accumulators
- Valves
- Conveyance

Landing Gear
- Cylinders & rods
- Struts
- Actuators
- Brakes
- Wheels
- Nose wheel steering

Interiors

Cabin Mgmt. Electronics

Cargo Systems

Lavatories

In-flight Entertainment
- IFE Systems
- Connectivity

Galleys
- Carts
- Heating & cooling

Structures
- Bins/stowage
- Panels
- Floors
- Monuments
- Crew rests

Seats
- Cockpit
- Crew
- Premier
- Economy

Avionics Systems

Aircraft Health & Monitoring
- Engine monitoring unit
- Aircraft health mgmt.
- Flight data recorder
- Cockpit voice recorder
- Quick access recorder
- Flight data acquisition unit
- Data busses and concentrators

Integrated Computing
- Computing/common core
- Network/AFDX

Communications
- VHF/HF
- Satcom
- ACARS router
- Antennae

Displays & Controls
- Primary displays
- Secondary displays
- Head-up display
- Pilot controls
- Panels & switches
- Electronic flight bag

Navigation & Surveillance
- Flight management systems
- Air data computer
- Inertial sensors
- RF sensors
- TCAS
- EGPWS
- Weather radar
- Enhanced vision
- Lidar

Aeroengines

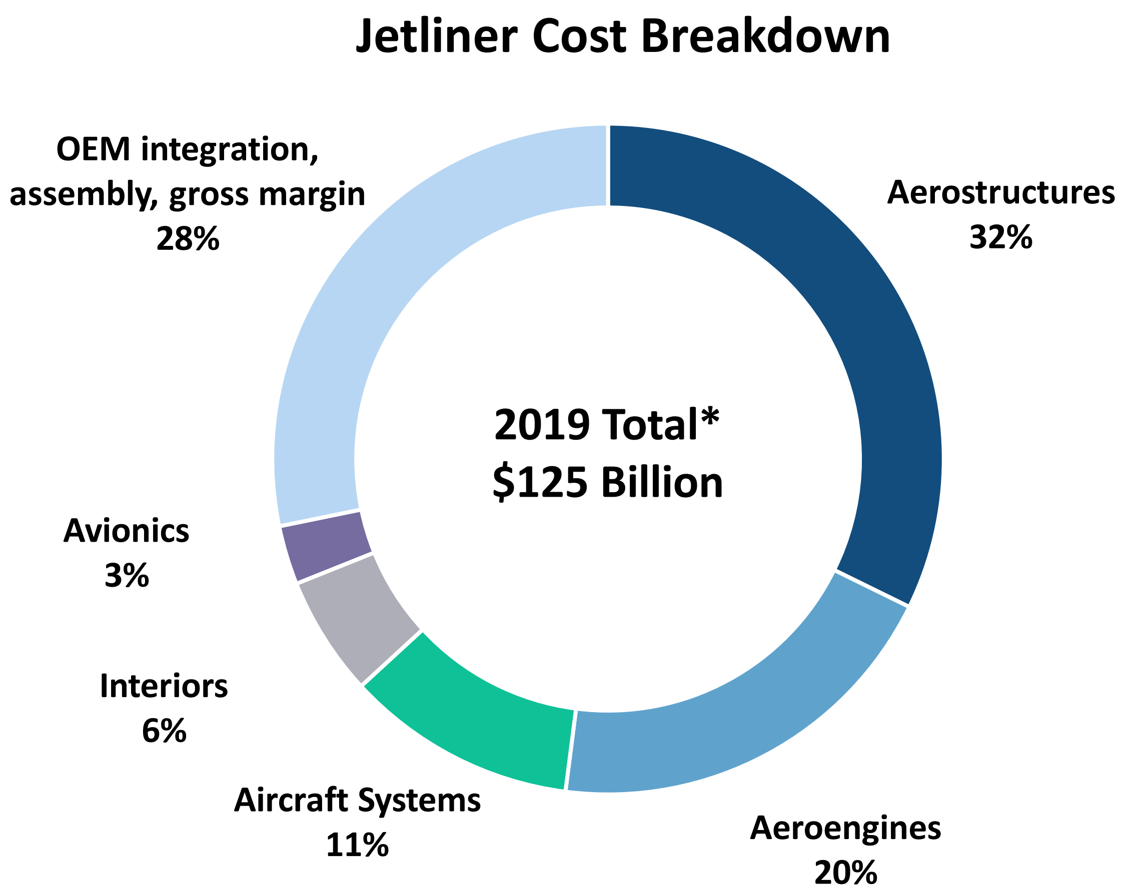
Blades & Vanes
- Fan
- Compressor
- Turbine
- Propeller

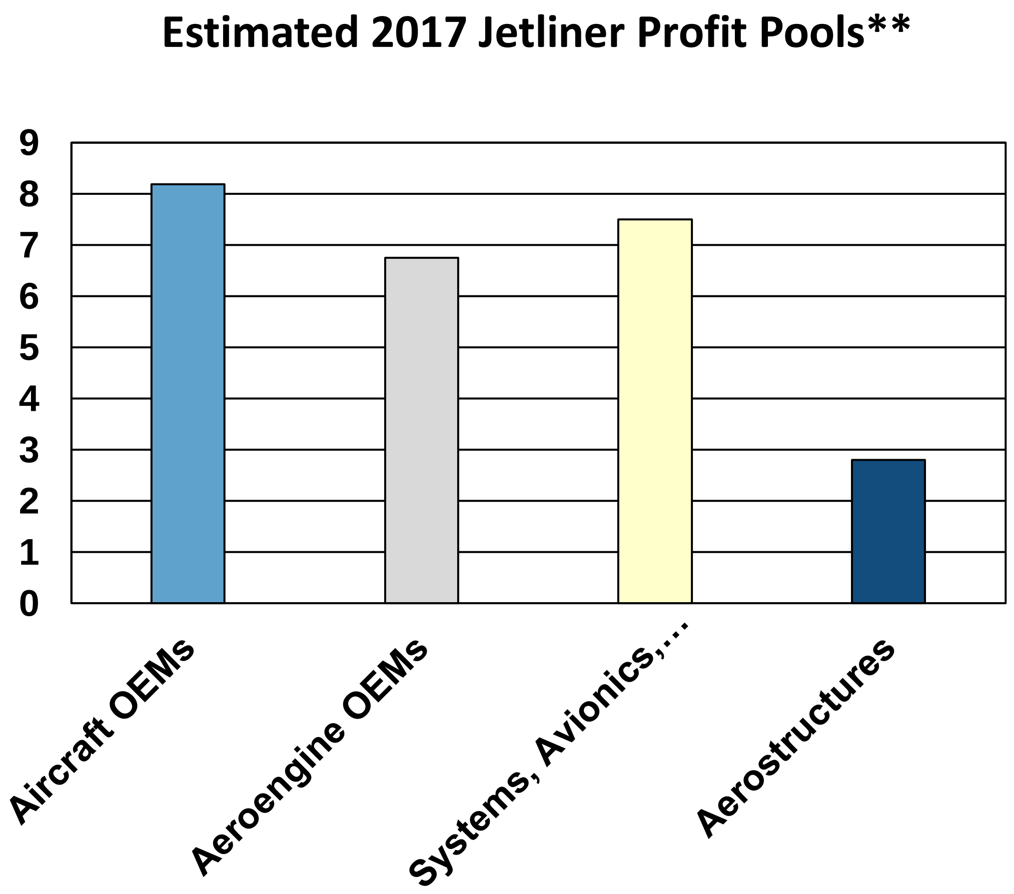
Life Limited Parts
- Rotors
- Shafts
- Hubs

Static Structures
- Frames
- Cases
- Combustors

Engine Accessories
- Gearboxes
- Starters
- Fuel control/FADEC
- Fuel nozzles
- Oil & pneumatic

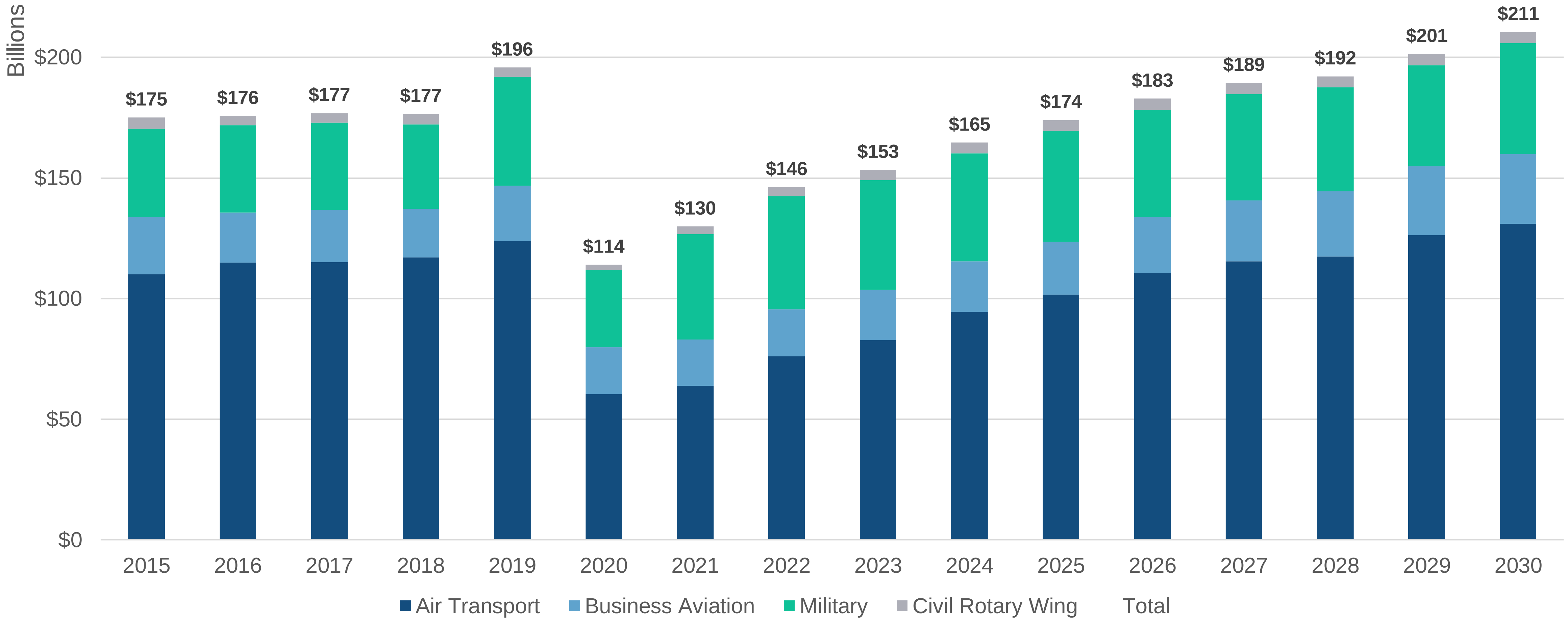
Structures and propulsion make up 50%+ of the typical commercial aircraft cost structure



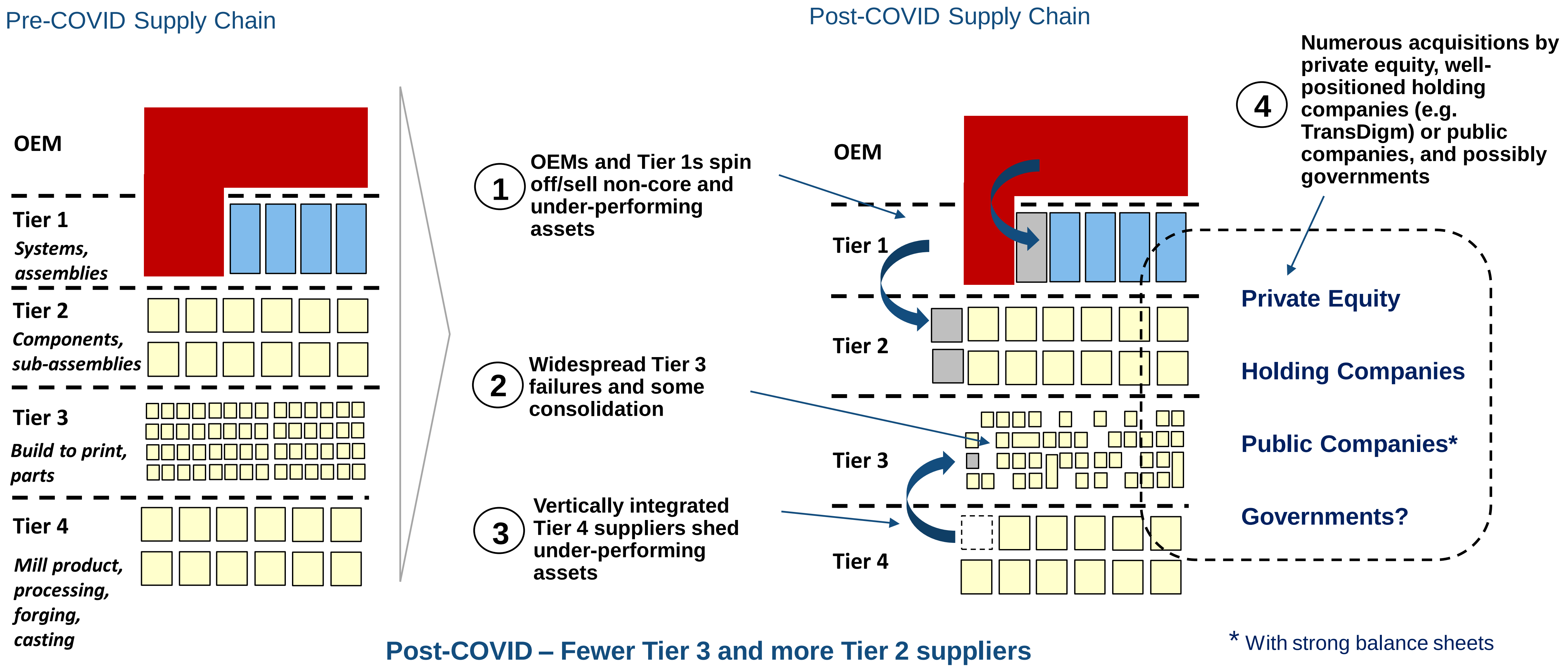


** Includes aftermarket

The aircraft production market was nearly $200B in 2019, falling to $114B in 2020; it will not recover to 2019 levels until 2028



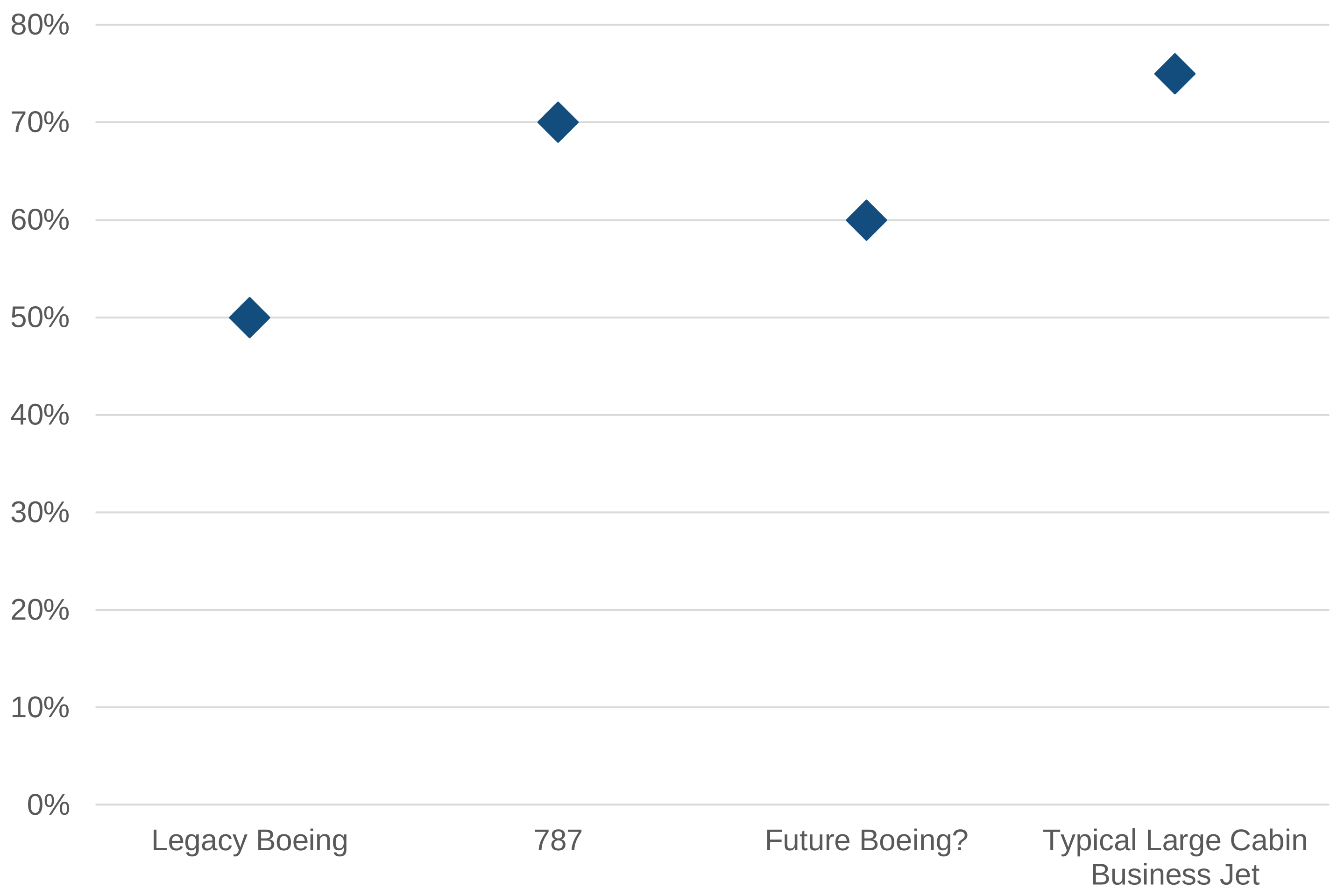
The COVID crisis will fundamentally restructure the aerospace ecosystem



Source: AeroDynamic Advisory

Business aviation OEMs typically source a higher percent of their cost structure and rely on Tier 1 integrators to provide large systems work packages

Percent of Cost Structure Outsourced by Aircraft OEM



- On legacy aircraft, Air Transport aircraft OEMs like Boeing and Airbus would design and produce over 50% of the aircraft cost structure in-house
- As the OEMs spun off some of their component design and manufacturing capability, the percent of aircraft cost produced in-house declined to ~50%
- On the 787, Boeing attempted to radically shift towards outsourcing, with major structures and systems outsourced to Tier 1 risk sharing partners
- Due to integration and supply chain problems on the 787, they will likely decrease outsourcing on future platforms
- Business aviation OEMs outsource many major structures and most systems to Tier 1 partners
- Due to their scale, they are laser focused on core competencies

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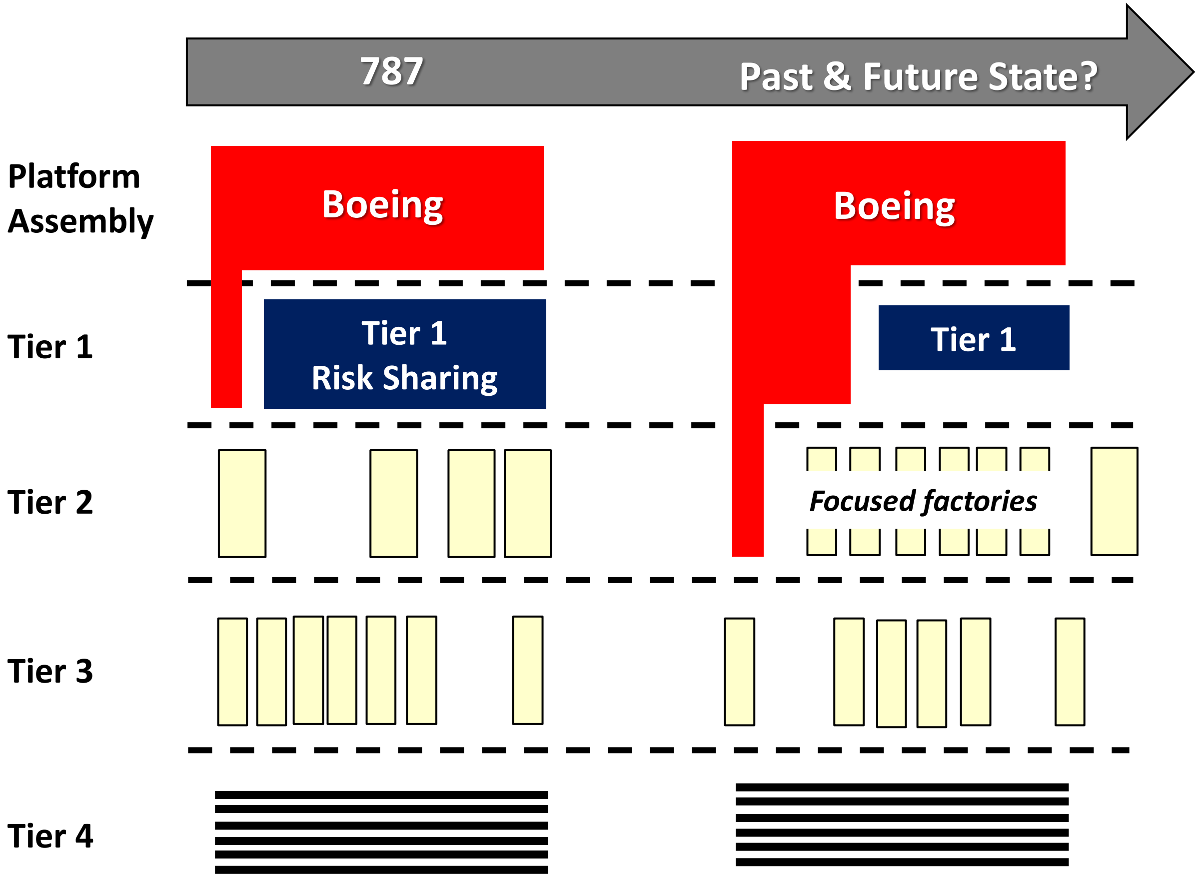
Pre-COVID, commercial aerospace OEMs were trending towards vertical integration; the post-COVID outlook is unclear



- Pre-COVID, aircraft OEMs (led by Boeing) were considering selective vertical integration
- This was being considered to:
  - Reduce risk in new aircraft development programs
  - Capture aftermarket value
  - Reduce Tier 1 systems and structure supplier leverage
- It is likely that the long-term COVID-19 production downturn will slow these plans somewhat

There are many aspects of structures and systems design that are not typically core to an aircraft OEM

Typically Core to Airframe OEM	Not Typically Core to Airframe OEM
› Overall vehicle design › Systems integration › Customer support (typically neglected by new entrants) › Vehicle final assembly › Avionics and computing architecture (increasingly core) › Autonomy & pilot interface design › Interior design (for business aviation OEM)	› Detailed structures design › Structures manufacturing › Detailed systems design (hydraulics, pneumatics, flight controls, actuation, landing systems, lighting, interiors) › Avionics, systems manufacturing › Propulsion system manufacturing (core to AAM)

Aircraft OEMs need to determine their core competencies and what capabilities truly differentiates their product performance, ability to execute, or profitability

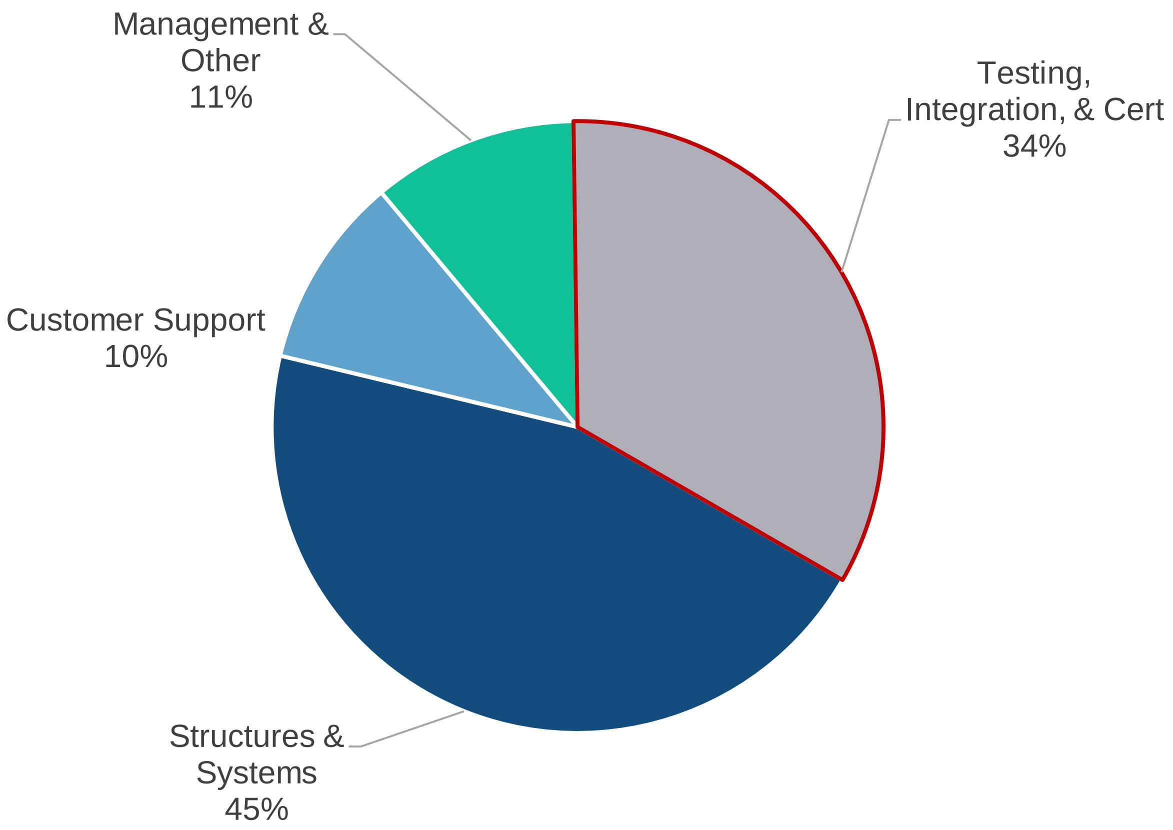
Aerospace Supply Chain Overview

Aircraft Development Programs – Lessons Learned

Potential Supply Chain Bottlenecks & Conclusions

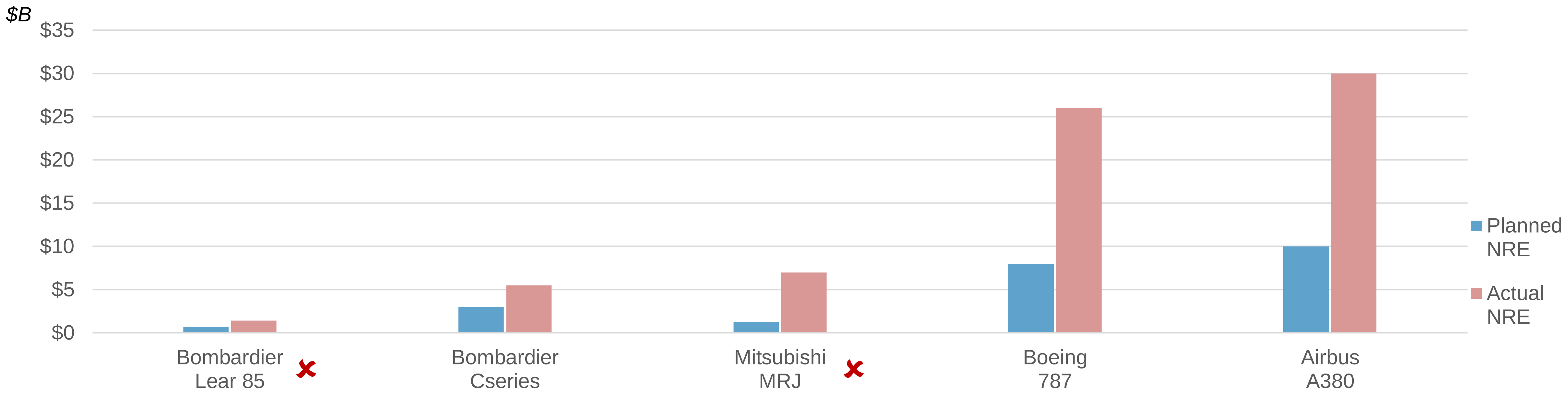
Testing, integration, and certification typically makes up a third of budgeted aircraft non-recurring costs

Typical Commercial Aircraft Program (Planned) Development Cost Breakdown



- Testing and certification is a significant piece of the aircraft program cost structure even if things go as planned
- In the event of issues, this integration, testing, and certification cost balloons and may dwarf all other program costs
- The actual “design engineering” on aerodynamics, systems, and structures represents less than 50% of the typical aircraft program development costs

Many new aircraft programs face significant development cost overruns, often driven by difficulties in testing and certification



Bombardier Lear 85
- NRE doubled original estimate before aircraft was cancelled
- Issues with first composite business jet fuselage

Bombardier Cseries
- Aircraft significantly over budget due to issues with fly-by-wire, engines, and structures
- BBD forced to JV program with Airbus for $1

Mitsubishi MRJ
- Inexperience with certification and documentation require
- Last budget estimate was nearly 600% of original budget; aircraft not certified
- Program "paused"

Boeing 787
- Significant systems redesign and supply chain delays
- Over 3X original budget estimate
- Delays and rework contributed ~$10B in costs on initial unsaleable aircraft

Airbus A380
- Significant redesigns needed with wing and wiring integration
- 3X original budget estimate
- Program shut down after short production run

Development cost overruns are common even among experienced aircraft OEMs

The Eclipse Aviation story is a cautionary note for new entrants in aerospace and aviation

Eclipse Story

- Eclipse Aviation was a new entrant in aviation started with the goal of producing a new category inexpensive Very Light Jets
- Eclipse planned on producing aircraft at a high production rate using increased automation with the goal of lowering manufacturing costs
- Operators relied on this low manufacturing and purchase price to underpin favorable operating economics
- However, the aircraft was delayed and ended up being much more expensive to manufacturing than planned, increasing the purchase price
- Operators like DayJet struggled with an unproven on-demand charter model, exacerbated by the Great Recession
- Eclipse entered Chapter 11 bankruptcy in 2008 and Chapter 7 liquidation in early 2009
- Subsequent attempts to restart production and provide aftermarket support to the existing fleet were largely unsuccessful

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The current environment creates many opportunities and threats for the AAM supply chain

Opportunities for AAM

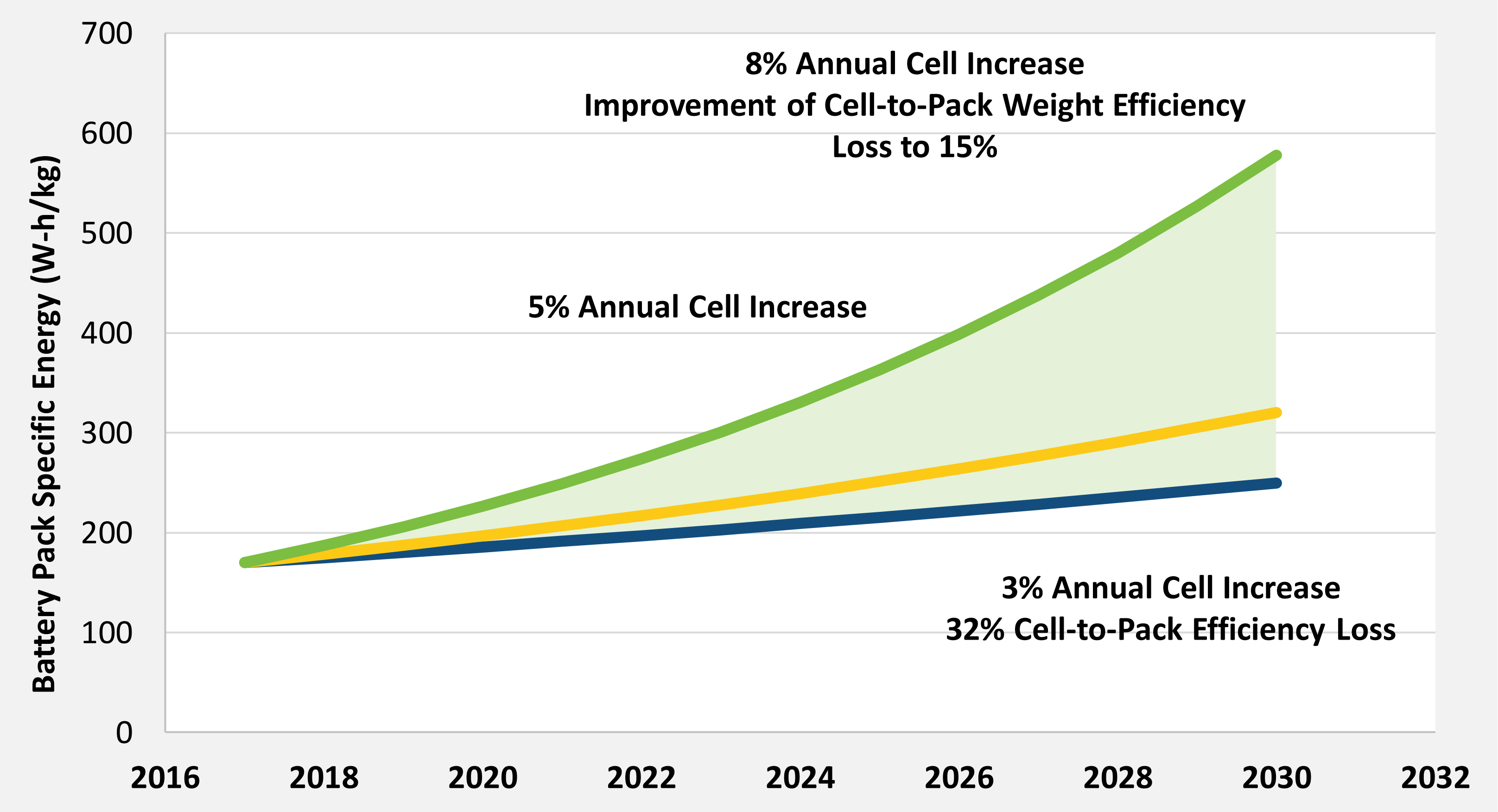
- Reduced volumes and continued profit pressure on commercial aerospace suppliers has them searching for adjacencies and innovative growth opportunities
- Suppliers are eager to explore AAM, but some are skeptical over business models, development/certification timelines, and cost expectations
- Leverage certification experience of incumbent aircraft OEMs and suppliers

Threats to AAM

- Certification is much more difficult than most new entrants realize – even without novel systems, propulsion technologies, or hybrid cert approaches
- In particular, certification processes are not set up to encourage rapid product iterations
- Automotive supply chains are battery-constrained; aerospace may have difficulty securing supplies to its specifications

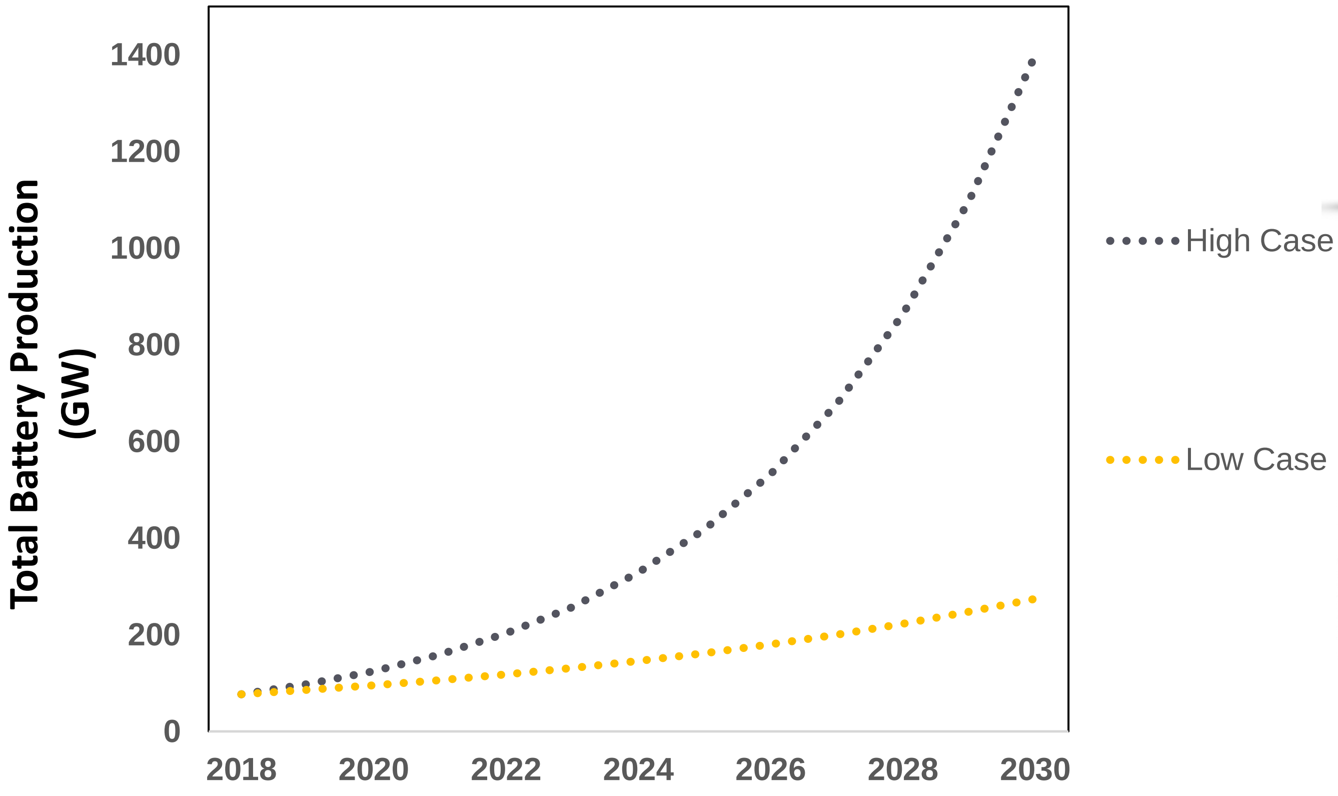
The threats to AAM are significant in the near-term, but COVID has produced some unique opportunities to attract the interest of the once capacity-constrained commercial aerospace industry

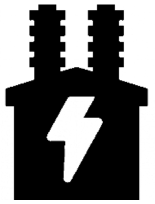
Battery energy density remains a significant bottleneck, although improvements are theoretically possible



- Current state-of-the-art Lithium ion batteries (Tesla automobiles and other electric vehicles) have a 250 W-h/kg specific energy at the cell level. This falls to approximately 170 W-h/kg with modern packing technology (32% loss)
- Recent trends indicate that cell level specific energy experiences an annual increase of 5%, predicting 320 W-h/kg battery packs by 2030 assuming no improvements to packing techniques
- Applying an optimistic annual increase of 8% at the cell level with packing loss reduction to 15% predicts a pack specific energy of 580 W-h/kg over the next ten years
- Significant advances in packing technology such as new cooling technology and new materials could reduce total system weight and improve annual gains

Global demand for lithium ion batteries will be driven by the automotive and energy storage markets

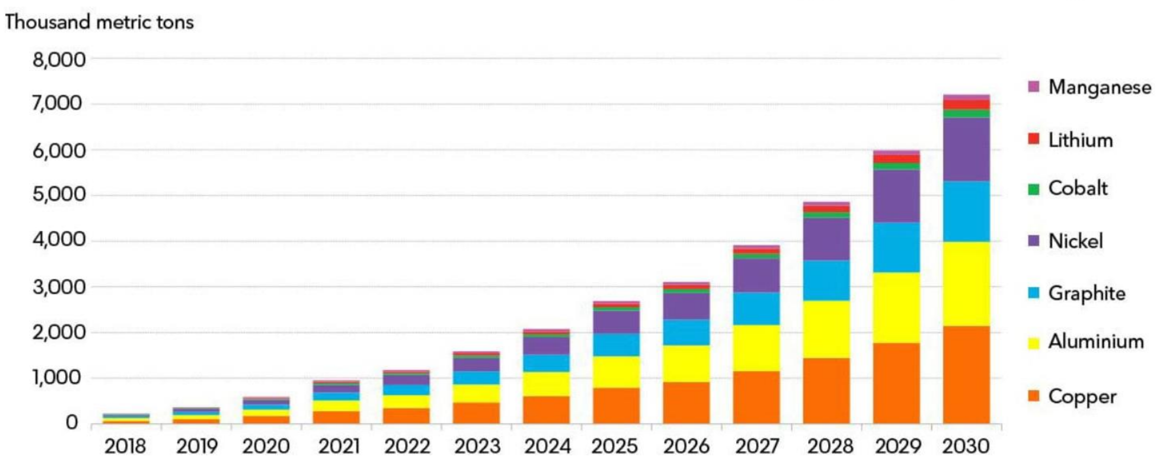




- The “high case” for global battery demand growth depends on the continued adoption of electric vehicles and subsequent displacement of combustion engine-powered vehicles
- In addition, the “high case” assumes increasing lithium battery-enabled grid storage systems will be installed in conjunction with renewables
- The low case also assumes significant growth in electric vehicles above today’s level, but less sustained displacement of traditionally powered vehicles
- Both scenarios assume growth in batteries for consumer electronics
- In any scenario, the aviation industry’s share of lithium-ion battery demand would be low (<5% even in the most optimistic adoption scenario)
- Therefore, aviation battery developments will depend heavily on advances from the automotive industry

Volatility in raw material input prices could have a significant impact on battery costs

Electric Vehicle Raw Material Outlook



- Raw material demand from electric vehicle batteries is expected to grow 20X+ from 2018 to 2030
- This increase in raw material demand will put significant pressure on existing players throughout the supply chain, from metal mining to processing, cell manufacturing, and pack assembly
- New battery architectures will likely have a different raw material mix
- In particular, the transition from lithium-ion batteries to solid state lithium-metal batteries could substantially increase lithium demand

Raw Material Price Impact on Final Cell Price

- Cobalt, Lithium, and Nickel costs have all risen in the past several years
- Global lithium is driven heavily by batteries
- Raw material prices are fairly volatile, and also subject to risk from tariffs/trade wars
- Battery manufacturers are developing architectures and manufacturing processes that use less raw material to insulate themselves from price increases (e.g. new batteries use 70% less Cobalt than previous versions)

Source: Bloomberg New Energy Finance

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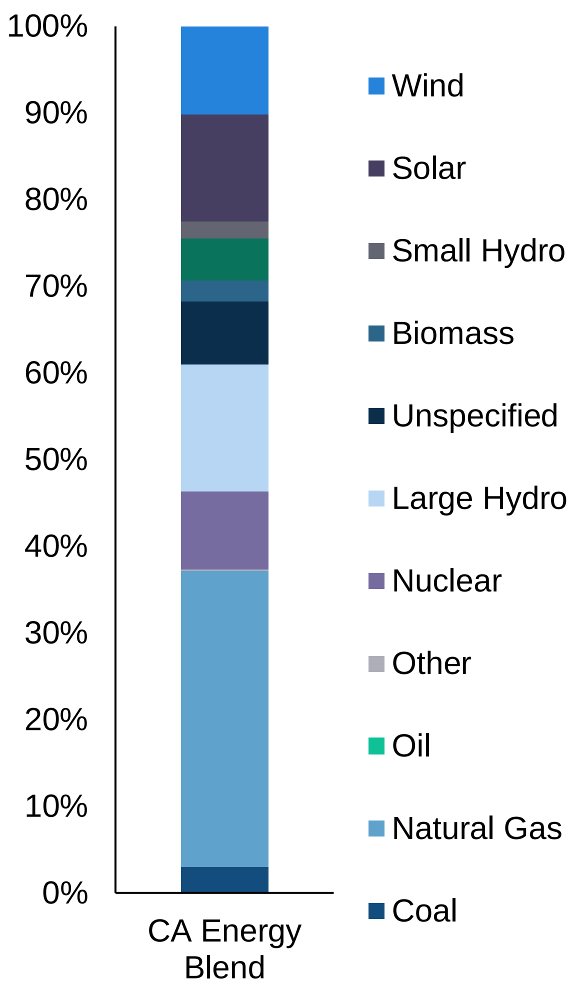
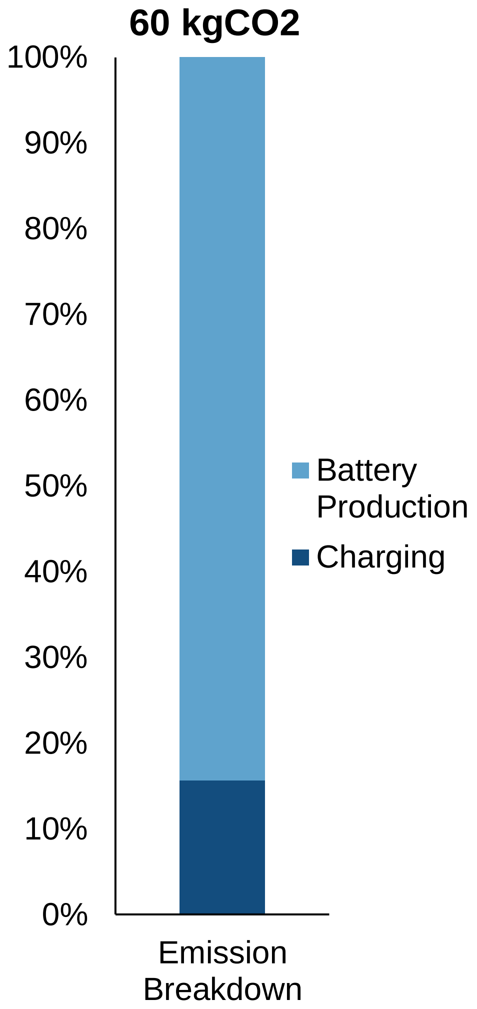
Increased emissions regulation/cost is a potential wildcard downside risk for AAM

Energy Overview

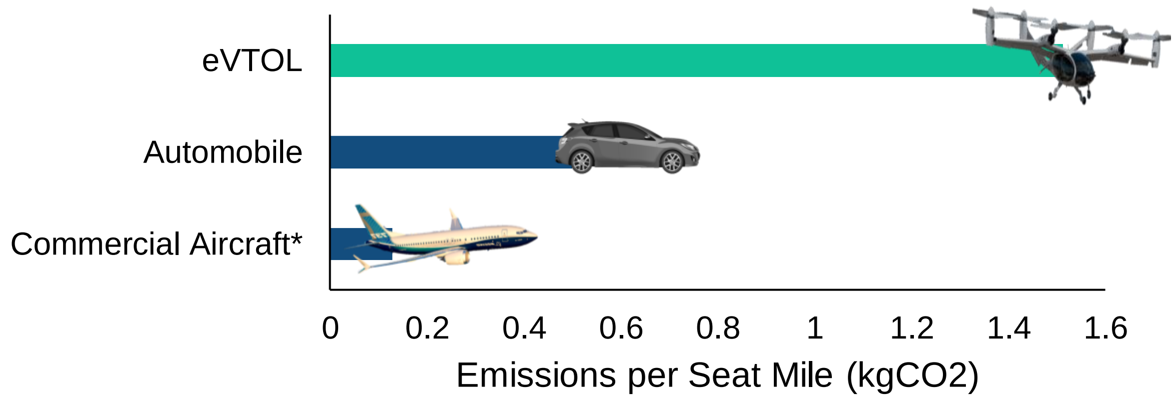




Commentary

- Since eVTOL aircraft do not burn any fossil fuels, their lifecycle emissions can be determined by the carbon footprint of lithium-ion battery manufacturing and disposal and by the energy blend where the batteries are charged
- At lower load factors, an eVTOL trip in San Francisco would generate about 1.5 kgCO2 per passenger mile. A 20-mile trip would emit 60 kgCO2 in total
- eVTOL emissions per passenger are much higher than emissions from automobiles and commercial aircraft
- Vertiport infrastructure can be retrofit with solar renewable energy to reduce charging emissions
- Many startups like Li-Cycle are investigating the potential of sustainably recycling lithium batteries and recovering 95% of materials

eVTOL Emissions Comparison



Source: EIA, Secondary Research
*NB 2000 mi flight

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